INFLUENCE OF SiC CONTENT ON MICROSTRUCTURES AND SLAG RESISTANCES OF LIGHTWEIGHT CORUNDUM-SPINEL CASTABLES

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ABSTRACT

Five lightweight corundum-spinel castables with different SiC content were fabricated using porous corundum-spinel ceramics as aggregates. Corrosion of the lightweight castables by ladle slag were conducted using the static crucible test. The effect of SiC content on the slag resistances of the lightweight corundum-spinel castables were investigated through SEM, EDS and FactSage® software, etc. It is found that the SiC powder can promote the sintering of the matrices of the castables in air atmosphere, decrease the median pore size of matrices and the apparent porosity of the castables, increase the SiO_2 content of the penetrated slag and then make the slag more viscous, and thus efficiently improve the slag resistance.

Keywords: lightweight corundum-spinel castables; SiC content; slag resistance; ladle slag

INTRODUCTION

Corundum-spinel castables have been widely used as working lining in ladle due to their excellent properties and easy installation [1]. With increased demand for saving high-quality resources and energy, more attention has been devoted to the researches on the lightweight refractories for working linings of industrial furnaces [2]. In order to fabricate the lightweight corundum-spinel castables, the bulk density of dense aggregate must be decreased. The decreasing bulk density of aggregate may affect the slag resistance of castables, which determines whether the lightweight castables could be used as working lining of ladle or not.

In the early work [3-6], the porous corundum-spinel ceramics have been prepared through an in-situ decomposition pore-forming technique, which is an excellent lightweight aggregate for fabricating lightweight refractories. In order to improve the slag resistance of lightweight corundum-spinel castables, additives are needed to adjust the microstructure and composition of matrix. SiC has lower wettability by molten slag, after it’s reaction with slag, the viscosity of penetrated slag would be increased resulting from the increase of SiO_2 content, and thus the penetration of the slag would be inhibited. But until now, the effect of the SiC content on the slag resistance of lightweight corundum-spinel castables using porous corundum-spinel ceramics as aggregates has not been understood. This will be addressed in the present work.

EXPERIMENTAL PROCEDURE

Five lightweight castables were prepared by using porous corundum-spinel ceramics (60.1 wt%, 5-0.088mm) as aggregate, and using 90 spinel powder (11.0 wt%), corundum powder and SiC powder (13.8 wt%), magnesia powder (3.9 wt%), α-Al_2O_3 micropowder (8.3 wt%) and SECAR71 cement (3.0 wt%) as matrix, through changing the SiC content (0, 0.5, 1.4, 1.8 and 2.8 wt%), named as A, B, C, D, and E respectively. The apparent porosity and bulk density of the aggregate were 41.0 % and 2.12 g/cm^3, respectively. The raw materials were mixed homogeneously with 12.2 wt% addition water, and then were casted into the rectangle parallelepiped samples (125 mm × 25 mm × 25 mm) for the measurement of apparent porosity, bulk density and phase composition, and the cubic crucible samples (70 mm ×70 mm× 70 mm, with a 30 mm diameter and 40 mm depth hole) for the static crucible test. The samples were cured for 24 h at room temperature, dried at 110 ℃ for 24 h. The dried samples and cubic crucible samples (filled with 30 g slag) were heated at 1600 ℃ for 3h in an electric furnace, then cooled down to room temperature. The chemical compositions of the ladle slag were 3.44 wt% Al_2O_3, 10.51 wt% SiO_2, 44.75 wt% CaO, 9.27 wt% MgO, 0.61 wt% TiO_2, 29.08 wt% Fe_2O_3 and 2.40 wt% MnO.

The apparent porosities and bulk densities were measured based on Archimedes' principle with water as the medium. The actual corroded and penetrated areas in each sample were measured by the counting pixels method [7]. The phase compositions were characterized by an X-ray diffractometer (Philips Xpert TMP) with a scanning speed of 2 °min^{-1}. The microstructures and compositions were measured by a scanning electron microscope (SEM, JSM-6610, JEOL Company, Japan) equipped with an energy dispersive spectrometer (EDS, QUANTAX200-30, BRUKER Company, Germany). The pore size distributions and median pore sizes of the matrices and aggregate were statistically analyzed through an image analysis method [8]. The reactions of the matrices and ladle slag as well as the viscosities of the glass phase at 1600 ℃ were simulated by the Equilib and Viscosity modes of the FactSage® thermo-chemical software (version 6.2), respectively.

RESULTS AND DISCUSSION

Fig. 1 gives the relationship of apparent porosity and bulk density with SiC content. After sintered at 1600 ℃, with an increase of SiC content, the apparent porosity declined from 42.2 % to 29.2 % and the bulk density increased from 2.12 to 2.49 g/cm^3.

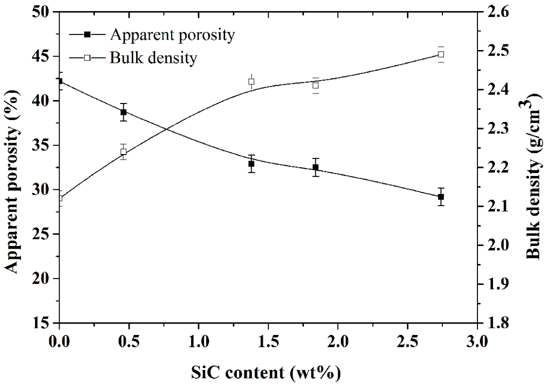

Fig. 1 Variation of apparent porosity and bulk density with SiC content.

Fig. 2 shows the XRD patterns of the five castables sintered at 1600 ℃. It is noticed that the main phase compositions of the five castables were corundum and spinel. When the SiC contents were 0wt% and 0.5 wt%, the cement reacted with Al_2O_3 of matrices to form a small number of CA_6. However, when the SiC content increased from 1.4 wt% to 2.8 wt%, the SiC was oxidized to form SiO_2, and then reacted with CaO and Al_2O_3 in matrices to form an anorthite phase with a low melting point.

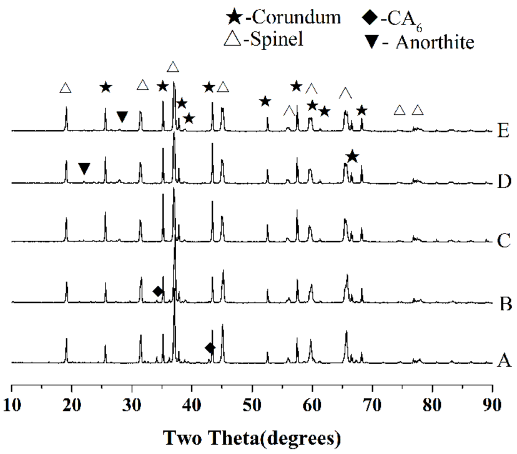

Fig. 2 XRD patterns of five castables sintered at 1600 ℃

The pore size distributions and microstructures of the matrices and aggregate are given Figs. 3 and 4, respectively. Bimodal distributions were observed among all matrices and aggregate. The large peak of the pore size distribution located at about 10-60 μm, while a very small peak located at 0.2-2.0 μm. With an increase of SiC content, the curves shifted towards the left, and the large peak value decreased. The median pore sizes of the aggregate, and the matrices A, C and E, were 12.6 μm, 22.0 μm, 16.3 μm and 15.6 μm, respectively.

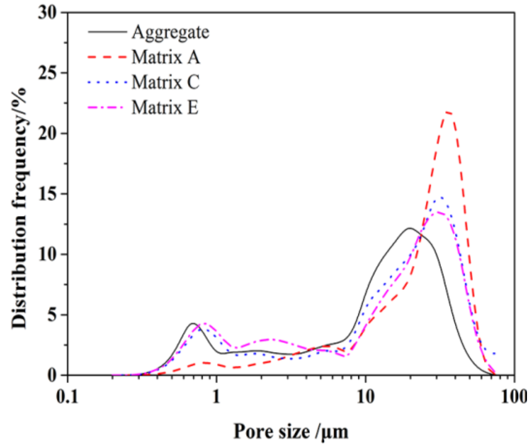

Fig. 3 Pore size distributions of the matrices and aggregate of the sintered samples

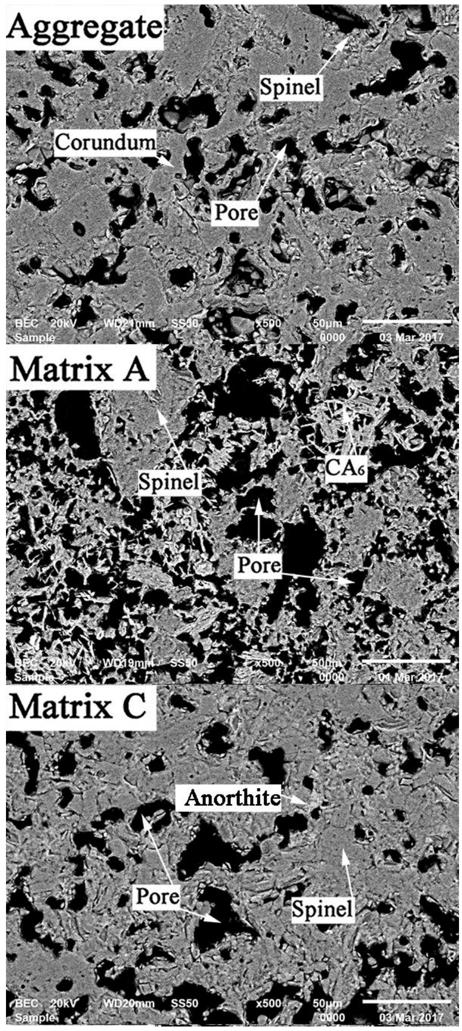

Fig. 4 Microstructures of the matrices and aggregate of the sintered samples.

The corrosion and penetration indexes of the corroded samples are shown in Fig. 5. When the SiC content increased from 0 to 2.8 wt%, the corrosion and penetration indexes greatly decreased. It indicates that the addition of SiC efficiently improve the slag resistances of the lightweight corundum-spinel castables.

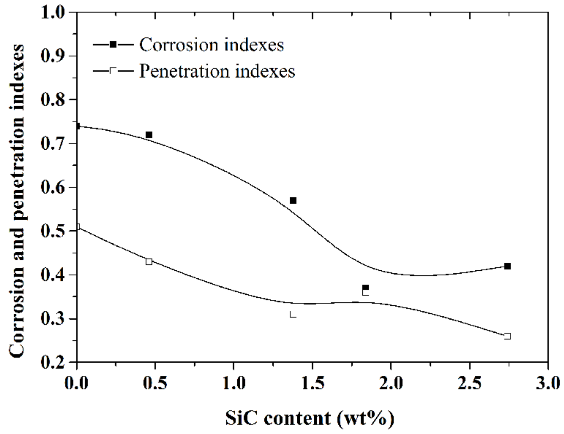

Fig. 5 Corrosion and penetration indexes of the corroded samples

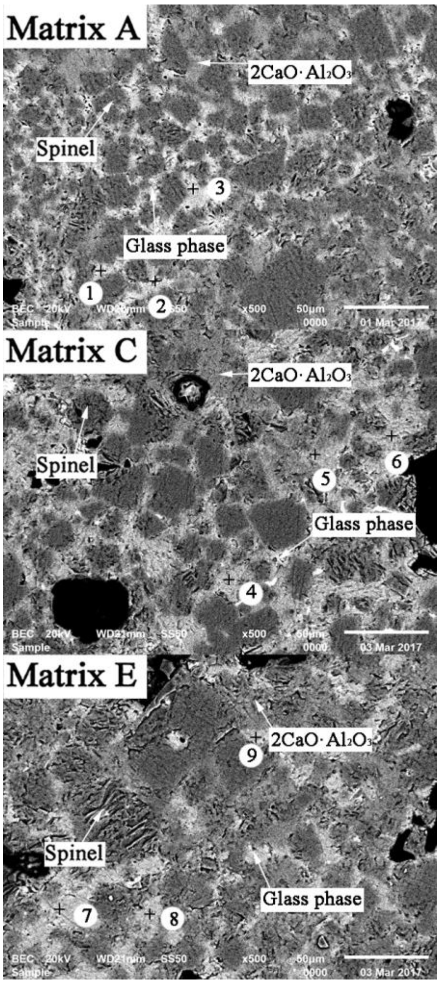

Fig. 6 Typical SEM micrographs of matrices at the hot face of corroded castables A, C and E

Microstructures of the matrices at the hot face of corroded samples A, C and E are shown in Fig. 6, and the EDS results and viscosities of the glass points in Fig. 6 are given in Tab. 1. In corroded matrices A, C and E, the glass phases mainly consisted of Al_2O_3, CaO, SiO_2, and Fe_2O_3, along with minor MgO, MnO and TiO_2. Oxide contents of the glass phases were different, which led to a bigger difference among the viscosities of the glass phases. With an increase of the SiC content from 0 to 2.8 wt%, the SiO_2 content of glass phase in the matrix increased, whereas, the Fe_2O_3 content decreased gradually. Therefore, the average viscosities of the glass phase in matrices A, C and E are 0.105 Pa·s, 0.122 Pa·s and 0.136 Pa·s, respectively.

Tab. 1 EDS results and viscosities of glass points marked in Fig. 6 at 1600 ℃

		A Matrix			C Matrix			E Matrix		
Points	Glass phase	1	2	3	4	5	6	7	8	9
EDS results (wt%)	Al_2O_3	34.17	34.77	36.54	33.46	36.28	34.13	35.27	34.04	34.48
	CaO	43.17	39.04	40.00	44.82	42.71	44.03	46.68	45.10	43.53
	MgO	2.20	2.00	1.98	2.26	3.30	2.70	1.65	1.97	2.17
	SiO_2	8.66	8.45	8.68	13.82	12.25	13.19	16.40	15.88	16.95
	MnO	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TiO_2	0.76	2.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fe_2O_3	10.20	13.57	12.01	5.64	5.46	5.94	0.00	3.01	2.88
Viscosities (Pa•s)		0.105	0.104	0.106	0.121	0.125	0.121	0.14	0.131	0.136
Average values of viscosities (Pa•s)		0.105			0.122			0.136		

The reaction process between the castables and ladle slag could be well-explained by the FactSage® thermo-chemical software. Considering SiC was not found in the XRD result (Fig. 2) and the microstructures (Fig. 4), it assumed that SiC had been oxidized completely in present work. The relationship between the weight of the predicted species and the glass viscosity with Beta, which denotes the weight ratio of the ladle slag to the castables matrices, is shown in Fig. 7. The reactants in the reaction process were 100 g matrix (A and E) and 0-200 g ladle slag. It can been seen from Fig. 7 (a and b), at 1600 ℃, the matrix A consisted of spinel, CA_6 and small amount of slag, whereas, the matrix E consisted of spinel, slag and small amount of corundum. With an increase of Beta value, the weight of CA_6 of matrix A drops to zero at Beta of 0.2, the weight of corundum of matrix E drops to zero at Beta of 0.1, and the weights of spinel of matrices A and E drops to zero at

Beta of 1.5 and 1.6, respectively. It means that the rate of CA_6 and corundum dissolving into slag is much higher than that of spinel. At the same Beta value, the SiO_2 content and viscosity of glass phase in matrix E are much higher than matrix A. Comparing the compositions of slag in matrices A and E in Tab. 1 with those in Fig. 7 (a and b), it is found that the simulation results are in great agreement with the experimental results.

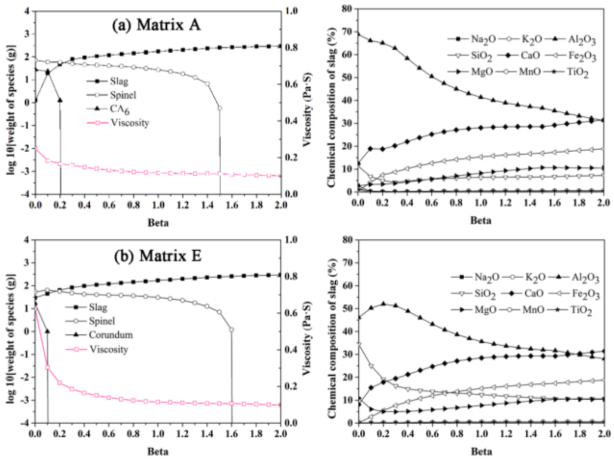

Fig. 7 Relationship between the weights of the predicted species and glass viscosity with Beta at 1600 ℃.

The slag resistance of lightweight castables depends on the phase composition and pore characterization of matrices due to their same aggregate. When the SiC content is 0 wt%, a small number of CA_6 was formed in matrix A, with the SiC content increasing to 1.4 wt%, the anorthite phase with a low melting point (1550 ℃) began to form in matrix C. At 1600 ℃, the anorthite phase existed in the form of slag (Fig 7), when contacted with the ladle slag, it would dissolve into the ladle slag directly and increase the viscosity of the penetrated slag. The decreasing median pore size of the matrices and the higher viscosity of the penetrated slag not only inhibited the penetration of slag, but also reduced the contact area between castables and slag to decrease the rate of spinel dissolving into slag, and thus improved the slag resistance.

CONCLUSIONS

The SiC content strongly affects the apparent porosity, the median pore size of matrix and the viscosity of penetrated slag, and thus affects the slag resistance. The following results can be obtained:

(1) The SiC in the samples were oxidized to SiO_2, and then promoted the sintering of the matrices, decreased their median pore size and the apparent porosities of samples.

(2) When the SiC content increased from 0 wt% to 2.8 wt%, the median pore size of matrices decreased gradually, the increasing SiO_2 content in the penetrated slag increased the viscosities, which both were beneficial to improve slag resistance.

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